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# Expendable Precision Laser Aimer for Shaped Charges

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# Expendable Precision Laser Aimer for Shaped Charges

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## Abstract

Certain shaped-charge cutting operations require a precision aiming system that is operationally convenient, robust, and constructed to allow the aiming system to be left in place for last-minute alignment verification until it is expended when the charge is fired. This report describes an aiming system made from low cost doubled-Nd:YAG 532 nm laser modules of the type used in green laser pointers. Drawings and detailed procedures for constructing the aiming system are provided, as are the results of some minimal tests performed on a prototype device.

## Introduction

It is common practice to use lasers for precision aiming of shaped charge jets. The laser aimers currently deployed suffer from two operational deficiencies: 1) The beam from the red diode lasers used in these aimers is difficult to see in some conditions, particularly in sunlight, and 2) They are attached to the shaped charge directly in line with the jet axis so they must be removed prior to firing the charge. Removal of the laser from the charge creates the possibility of accidental movement of the charge and precludes the possibility of verifying charge alignment immediately prior to firing the charge.

The laser aimer described in this report addresses the first deficiency by using low-cost doubled Nd:YAG (532nm) laser modules of the type used for green laser pointers. The responsivity of the human eye peaks near this wavelength, making light from these lasers much more visible for a given laser power, so that good visibility can be obtained with eye-safe Class 3a lasers. The second deficiency is addressed by using two laser modules mounted in the shaped charge holder, off-axis from the charge itself. These laser modules are modified so that each module produces a "line" of light on a target instead of a "dot". The modules are arranged so that the intersection of the two projected linear beams lies along the shaped charge jet axis. This arrangement leaves the jet path completely open so that the lasers can be left in place and illuminated from the initial alignment through the firing of the charge.

## Project

The requirement to leave the aiming system in place when the charge is fired places cost and configuration constraints on the expendable parts of the system. It is highly desirable that the aimer project an alignment beam exactly along the axis of the shaped charge, but at the same time it must not interfere with the formation or propagation of the jet, so the aimer must have little or no mass in the jet path.

To achieve these goals, the aiming system described here uses two low-cost green laser-pointer modules which are mounted near the shaped charge such that the laser beam axes are parallel to the shaped charge axis. The lasers are bonded into the same support that holds the charge so that this alignment is maintained. Each module is modified to produce a planar “fan” of light instead of the usual pencil beam. The “fan” of light produces a line when it strikes a target. The two modules are mounted so that the plane of each laser “fan” contains the shaped charge axis, and the two fans of light intersect at roughly 90°. Thus, the two lasers project a “crosshair” of light onto a target placed anywhere along the path of the jet. The intersection of the two lines of the “crosshair” marks the shaped-charge axis, and hence the jet path.

Testing of off-the-shelf green laser pointers revealed that there are two features of these devices that needed to be addressed. First, the laser beam is neither centered on the module’s physical axis, nor is it parallel to it. Second, while the modules work well at high temperatures (tested to 180°F), most will not work at temperatures below about 40°F. The failure at low temperatures is probably due to changes in the index of refraction of the frequency doubling crystal that converts the infrared 1064 nm light from the diode-pumped Nd:YAG laser into green 532 nm light.

These shortcomings are addressed by bonding a thin foil heater to the laser module and then mounting the module into a cylindrical glass-reinforced Delrin sleeve so that the laser beam is co-axial with the outside surface of the sleeve. The potting material used to stabilize the module in the sleeve has very low thermal conductivity, and provides thermal and impact protection to the laser module. A thermal controller built into the non-expendable power supply unit controls the heater current, ensuring that the laser module itself is maintained at an operable temperature.

Figure 1 shows a block diagram of the aiming system, Figure 2 shows a CAD solid model of the aimer concept, and Figure 3 shows a cutaway drawing of one of the laser modules mounted in the Delrin sleeve.

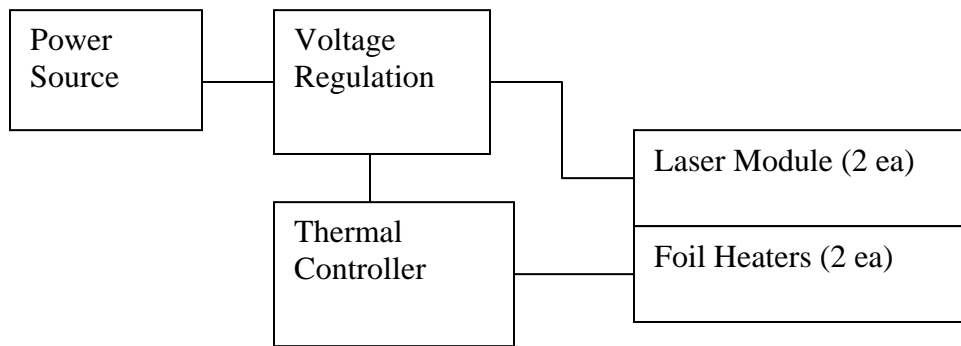


Figure 1 – Block diagram of Laser Aiming System

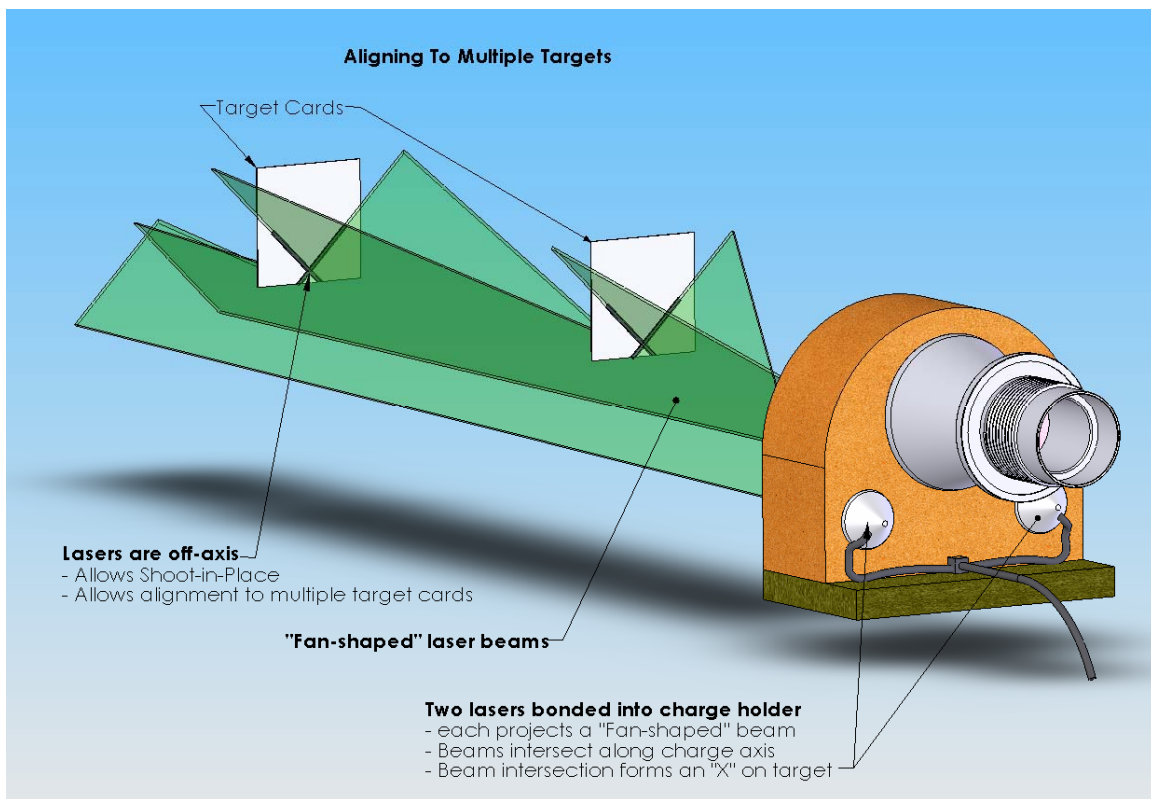


Figure 2 – Solid Model of Aimer Concept.

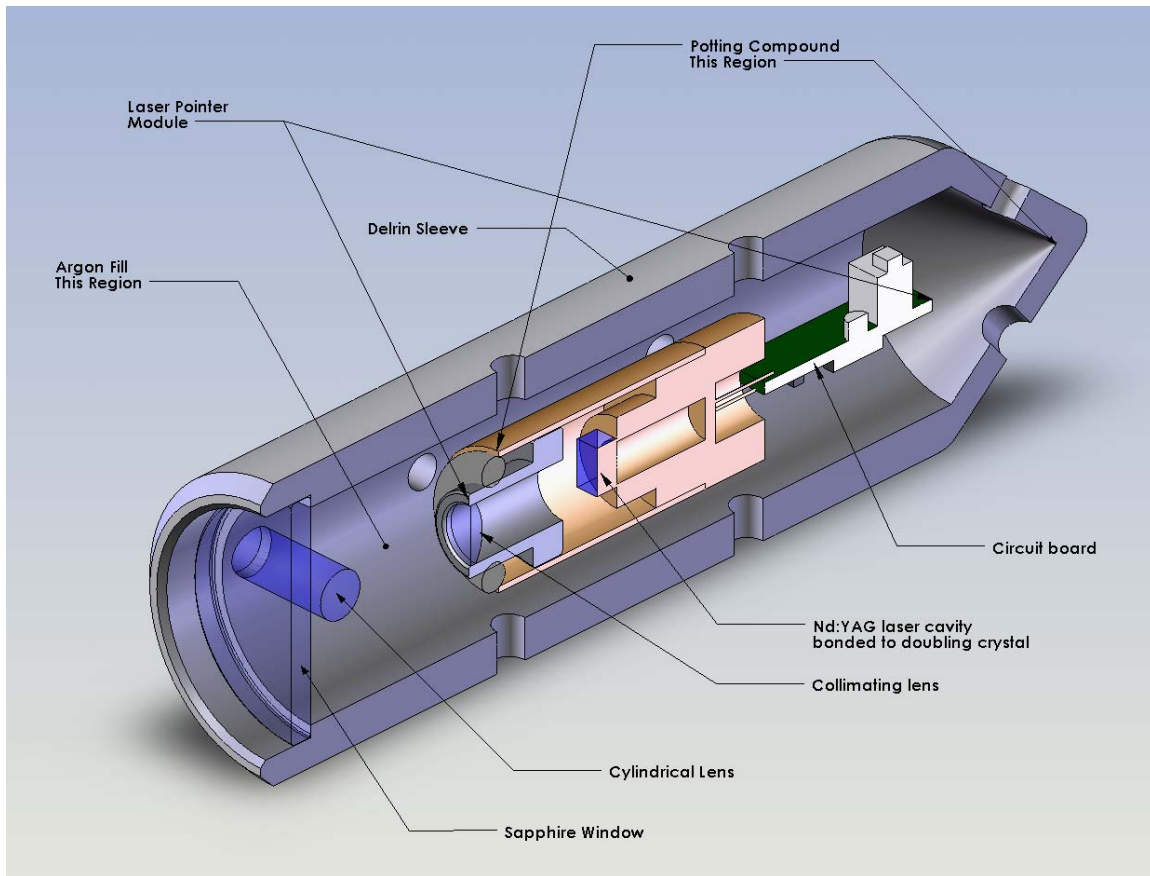


Figure 3 – Cutaway view of laser assembly in Delrin sleeve.

The thermal control circuitry requires 6 to 12 VDC of electrical power. The lasers themselves require 3 VDC. The main effort of this project was to develop the expendable portion of the aiming system, not the power supply, however one possible power supply arrangement that meets the requirement is shown in Figure 4. This power supply circuit is used to power the prototype aimer developed in this project.

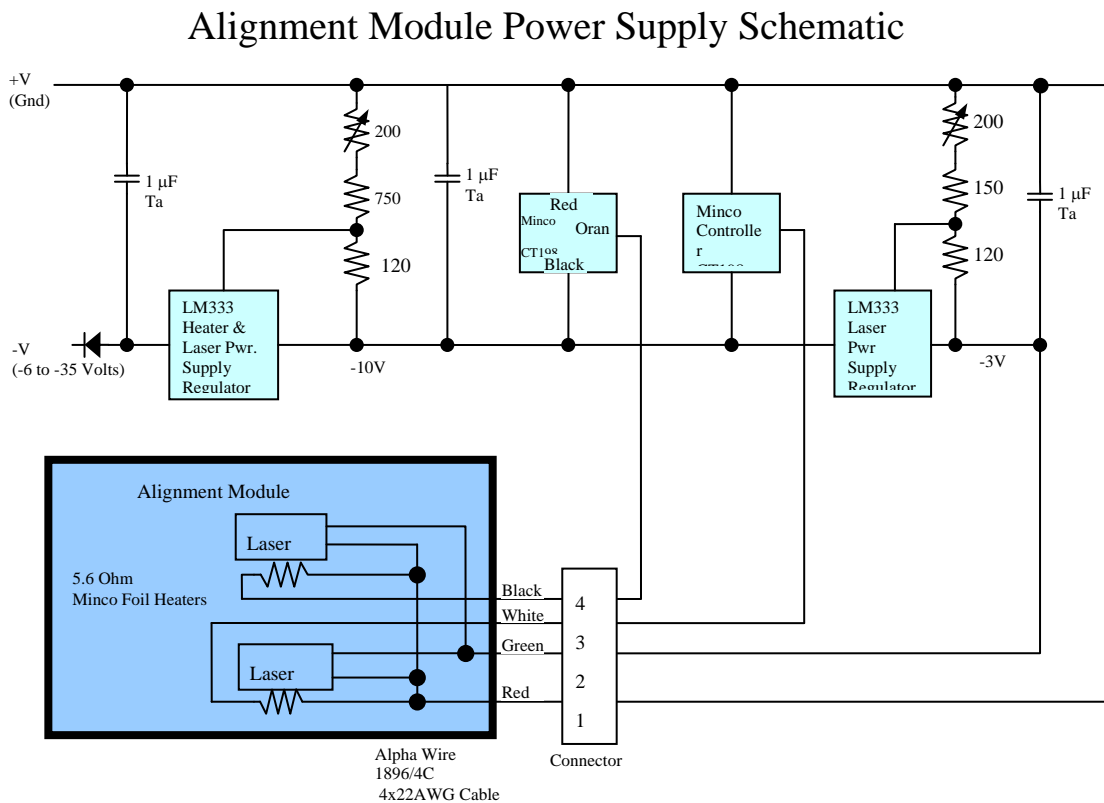


Figure 4 – Power Supply Circuit

The three deliverables of this project are: 1) Detailed design of the expendable portion of the aiming system, 2) Detailed procedures describing how to assemble and align the aimer, and 3) A prototype aimer for use in evaluating and testing the concept, and 4) Results from a few basic tests of the prototype, which include measurement of the accuracy of the alignment of the aimer to the shaped charge axis and minimal testing to see that the system will operate over the required temperature range.

Appendix 1 contains drawings for all components of the laser aimer. Appendix 2 gives a detailed assembly procedure for the aimer.

## Results

The design and assembly procedure was completed, a prototype aimer was built, and tests were performed to assess the basic alignment accuracy of the aimer. Additional testing verified that the aimer works over a wide temperature range.

Measurements of the alignment accuracy of the aimer show that the maximum discrepancy between the axis of the shaped charge axis as determined by the shaped charge mounting block and the intersection of the two aimer laser beams is less than 2 mm over the range from 0.1m to 5 m from the front of the shaped charge mount. This

corresponds to a maximum angular error of .4 mRadians, which is better than the design specification of 1 mRadian.

The prototype was tested over a temperature range of -20F to 160F. The prototype aimer worked well over this entire range. The lasers illuminate immediately when the temperature range is between 40F and 160F. When the aimer is cold, a warm-up period is required for the heaters to bring the laser modules up to the operating temperature. At -20F, this warm-up period approximately 1 minute.

Figure 5 shows the assembled aimer with the lasers operating. In the figure, an alignment tool is inserted in the shaped charge mount in lieu of an actual shaped charge. Note that the aimer can be aligned to two targets at different distances if the front target is kept small so that the laser light can propagate below it to strike the second target, as shown in the figure.



Figure 5 – Aimer with lasers illuminating two targets at different distances.

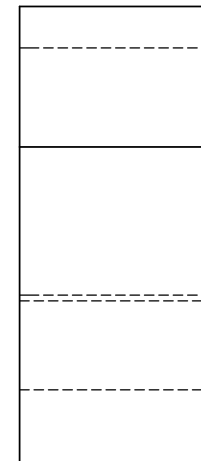
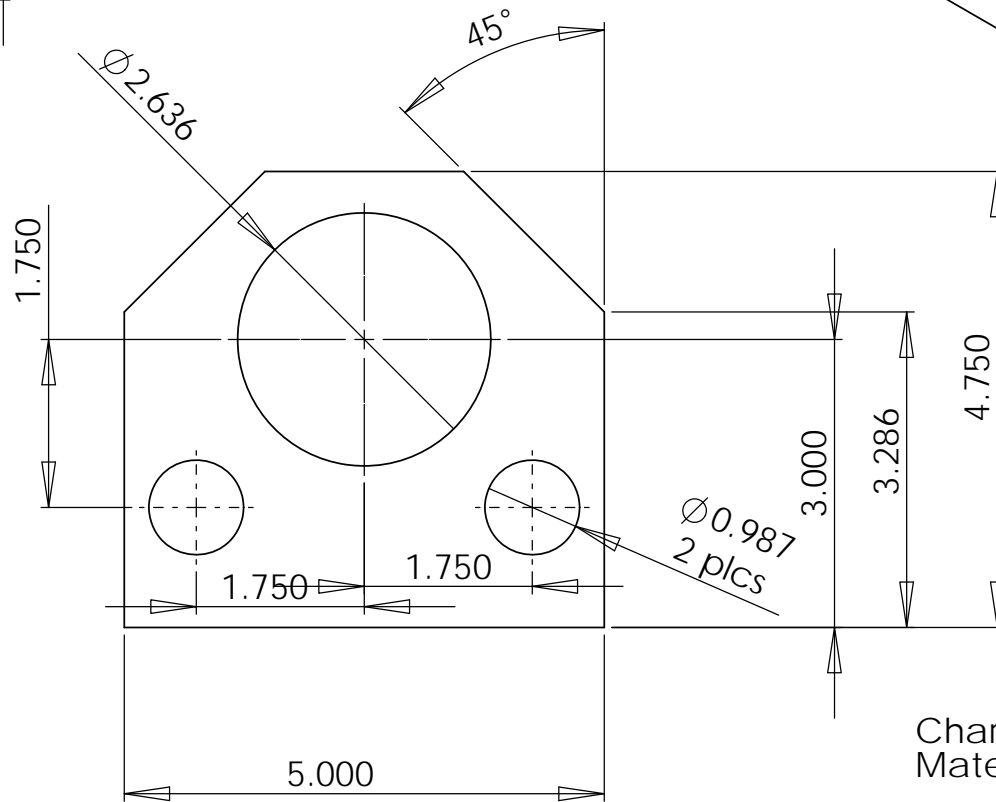
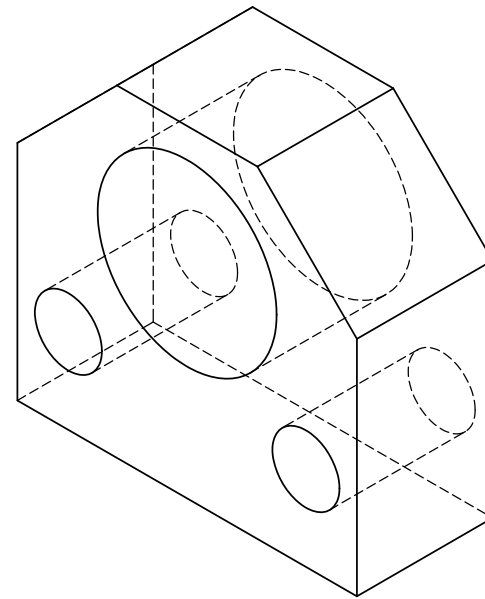
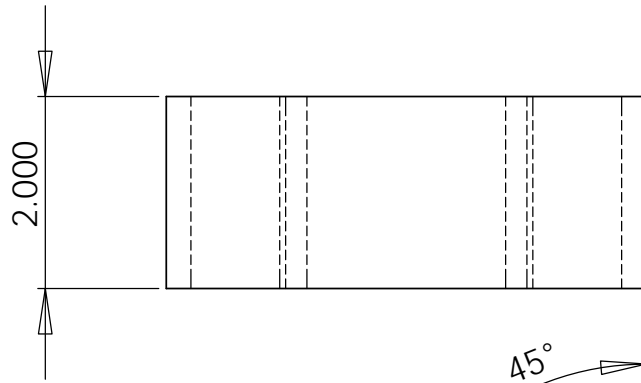
**Programmatic**

The FY07 milestones and deliverables were met. There are no FY-08 follow-on activities planned.

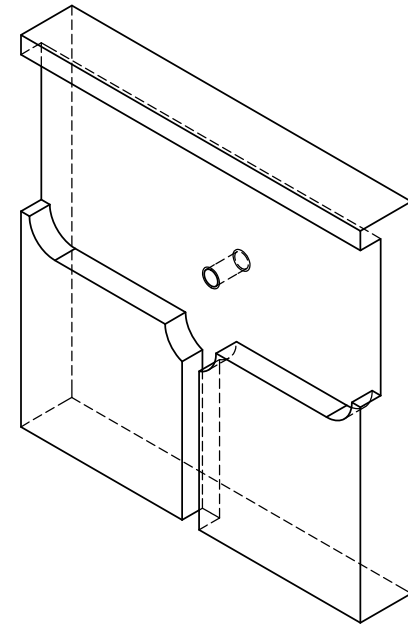
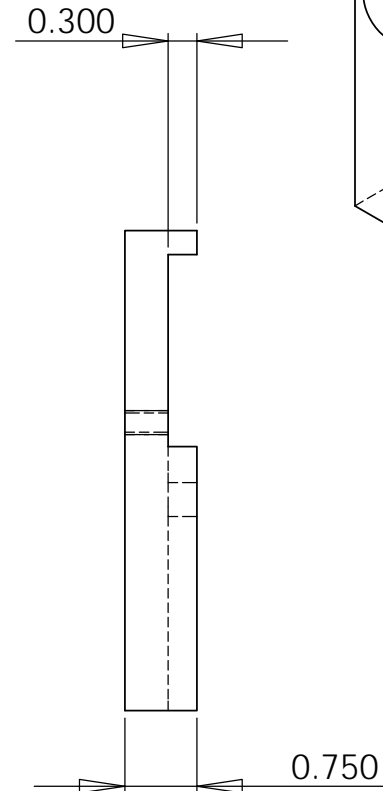
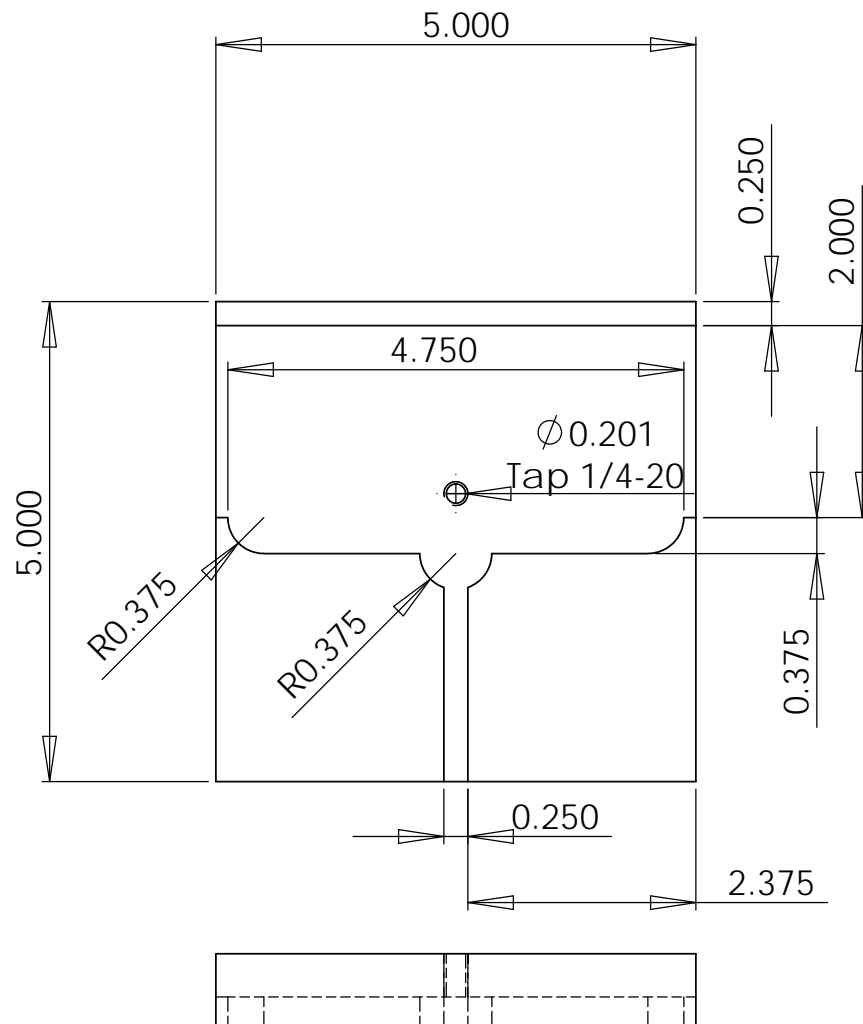
**Conclusion**

A precision laser aiming system for shaped charges that can be left in place when the charge is fired was designed and a prototype was built and tested for basic functionality. The prototype device met the design requirements of 1.0 mRadian pointing accuracy and operability over the temperature range of -20F to 160F.

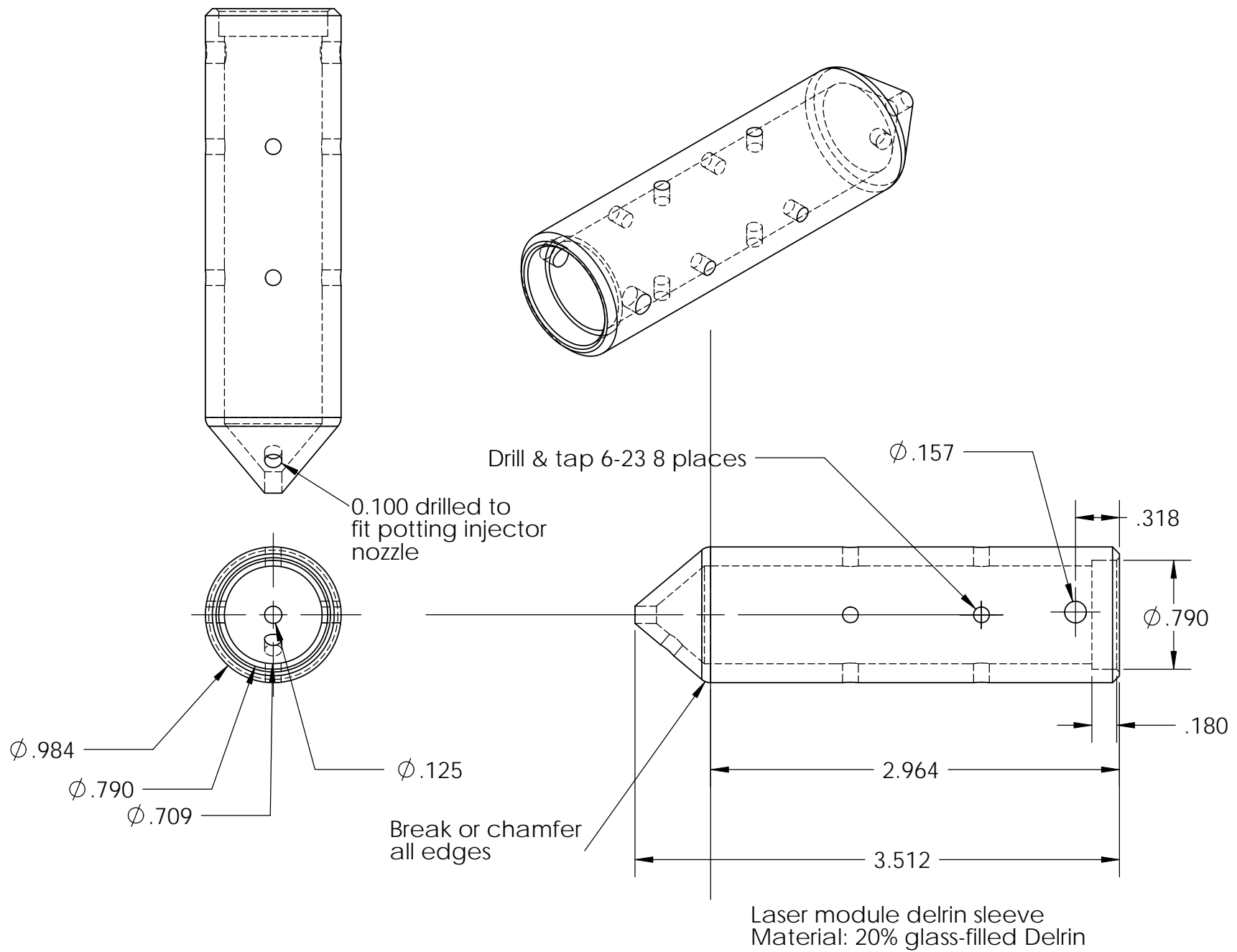
## **Appendix A - Drawings**

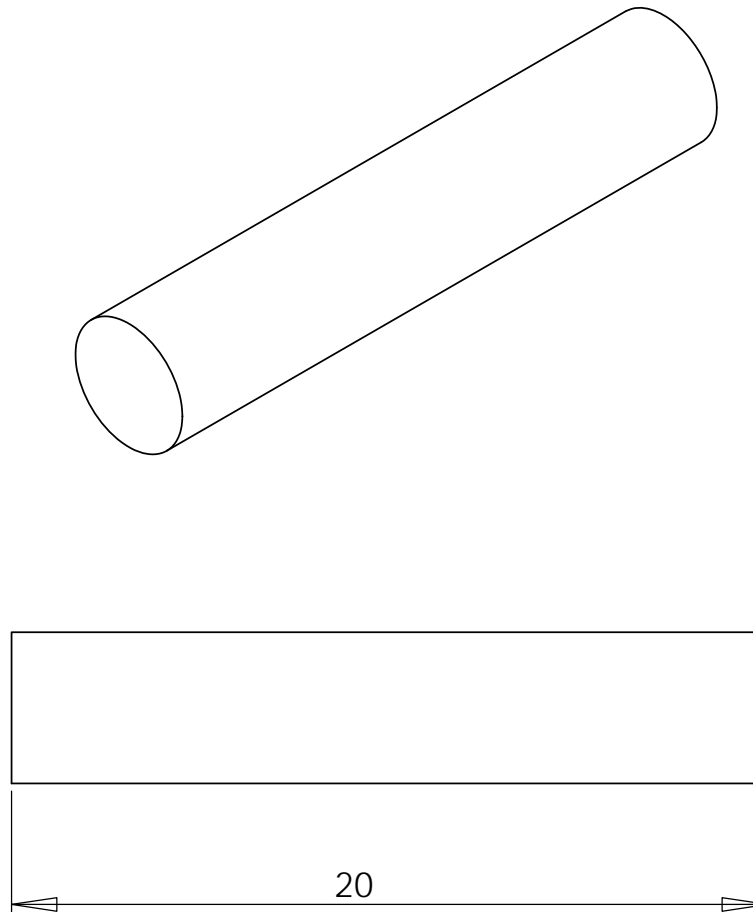
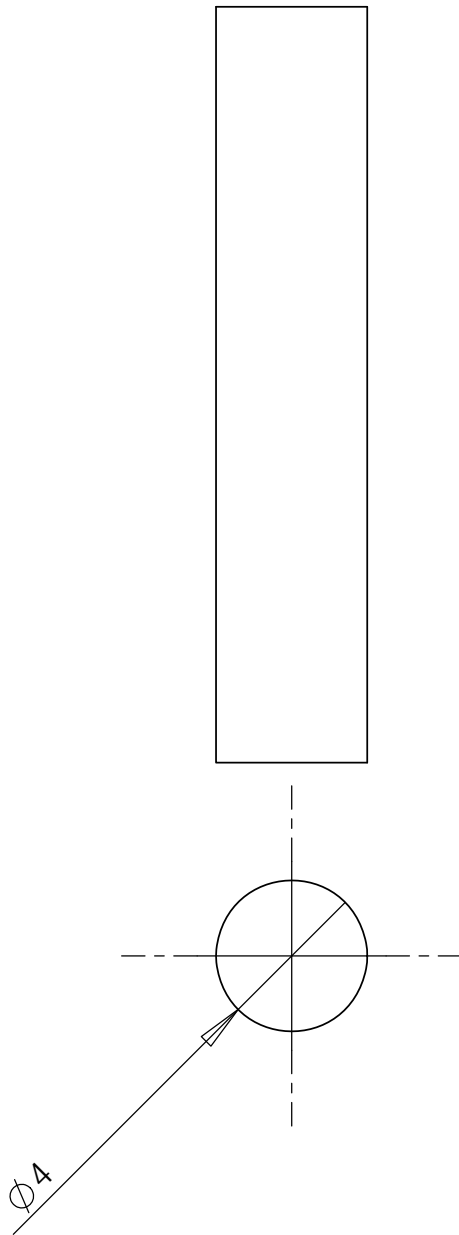


Charge Holder  
Material: 10# Last-a-Foam FR-6710

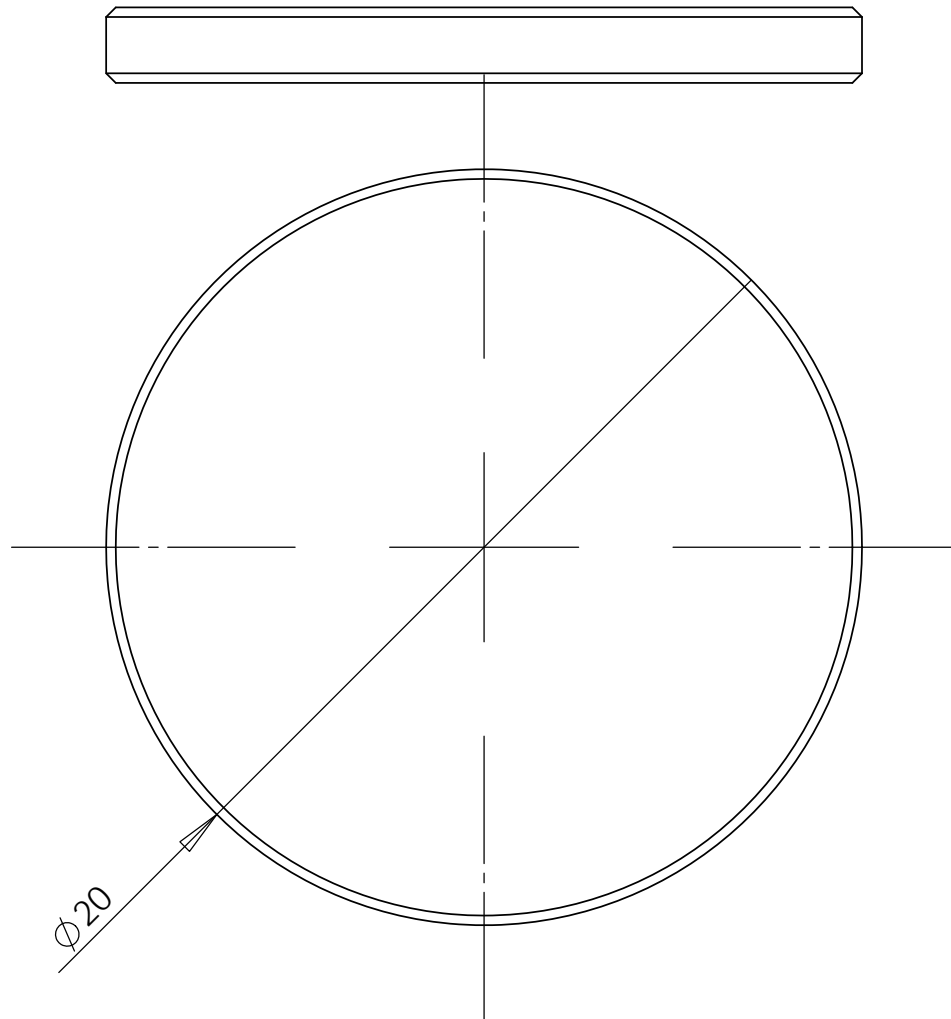


Charge Holder Base Plate  
Material: G-10 Epoxy board





Cylindrical Lens  
Material: BK-7 Glass  
Doric Lenses, Inc., Quebec, Canada  
(418) 877-5600  
[www.doriclenses.com](http://www.doriclenses.com)  
CYL\_ROD\_4.0\_4.0\_24.0



Sapphire Window  
Material: Sapphire  
Vendor: [www.optics-online.com](http://www.optics-online.com)  
Part # WSP-006

## **Appendix B – Laser Aimer Assembly Procedure**

### Leave-in-Place Precision Laser Aiming System for Shaped Charges

For detailed information about the components described in this section, please refer to the drawings in Appendix 1.

#### Basic Procedure

If buying in quantity, it is possible to purchase “bare” laser modules of the type used in laser pointers. For small production runs, however, it may be necessary to purchase laser pointers and disassemble them to get the modules. The procedure given here assumes that the modules must be removed from laser pointers, as was done for the prototype aiming system.

The basic steps for assembling the aimer are:

1. Disassemble the laser pointers, modify the body and circuit board, and reassemble the laser into the modified laser pointer body
2. Bond the foil heaters to the modified laser pointer body and install the wire pigtails.
3. Flex-mount the laser pointers into the Delrin sleeves for alignment
4. Rough align the laser pointers in the sleeves
5. Insert and bond the cylindrical lens into the Delrin sleeve
6. Final align the laser pointers in the Delrin sleeves
7. Permanently pot the laser pointers into the Delrin sleeve
8. Check alignment & test operation of assembled laser assemblies
9. Bond window into laser assembly
10. Align and bond laser assemblies in shaped charge holder
11. Connect and pot the laser assembly wiring
12. Install connector on laser/heater supply cable

#### Detailed Procedure

The step numbers used in this section are those given in the Basic Procedure Section.

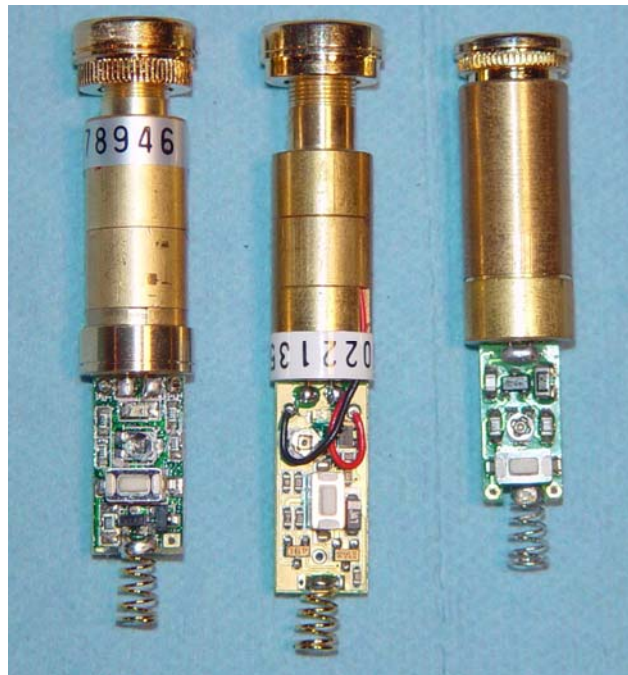
##### Step 1: Laser Pointer Module Disassembly & Modification

The figure below shows a typical green laser pointer in both the assembled and disassembled states.



The laser module itself is the brass-colored part with the circuit board attached. The laser module is pressed into the black metal tube body of the pointer so that about  $\frac{1}{4}$ " of the laser module is exposed. An easy way to pull the laser module from the body is to grip the brass end of the module in the collet of a lathe and grip the body (with the battery cover screwed in) in a chuck mounted in the tailstock of the lathe. The tailstock feed can then be used to pull the module out of the body. The press fit is only about  $\frac{1}{4}$ " long. Once the module comes loose from the body, release the parts from the lathe and pull the assembly apart by hand. On some laser pointers, there is a small LED that lights when the laser is on, and this indicator can make it difficult to pull the laser module out of the body. A firm push will pop this indicator down into the laser pointer body so that the module can be removed easily.

There are at least 3 different types of laser modules used in green laser pointers. The figure below shows three different styles:



Note that these modules are different lengths. Measure the length of the module, and use the lathe to cut the laser pointer body so that the end of the circuit board (not including the spring) will be about  $\frac{1}{4}$ " inside the tube.

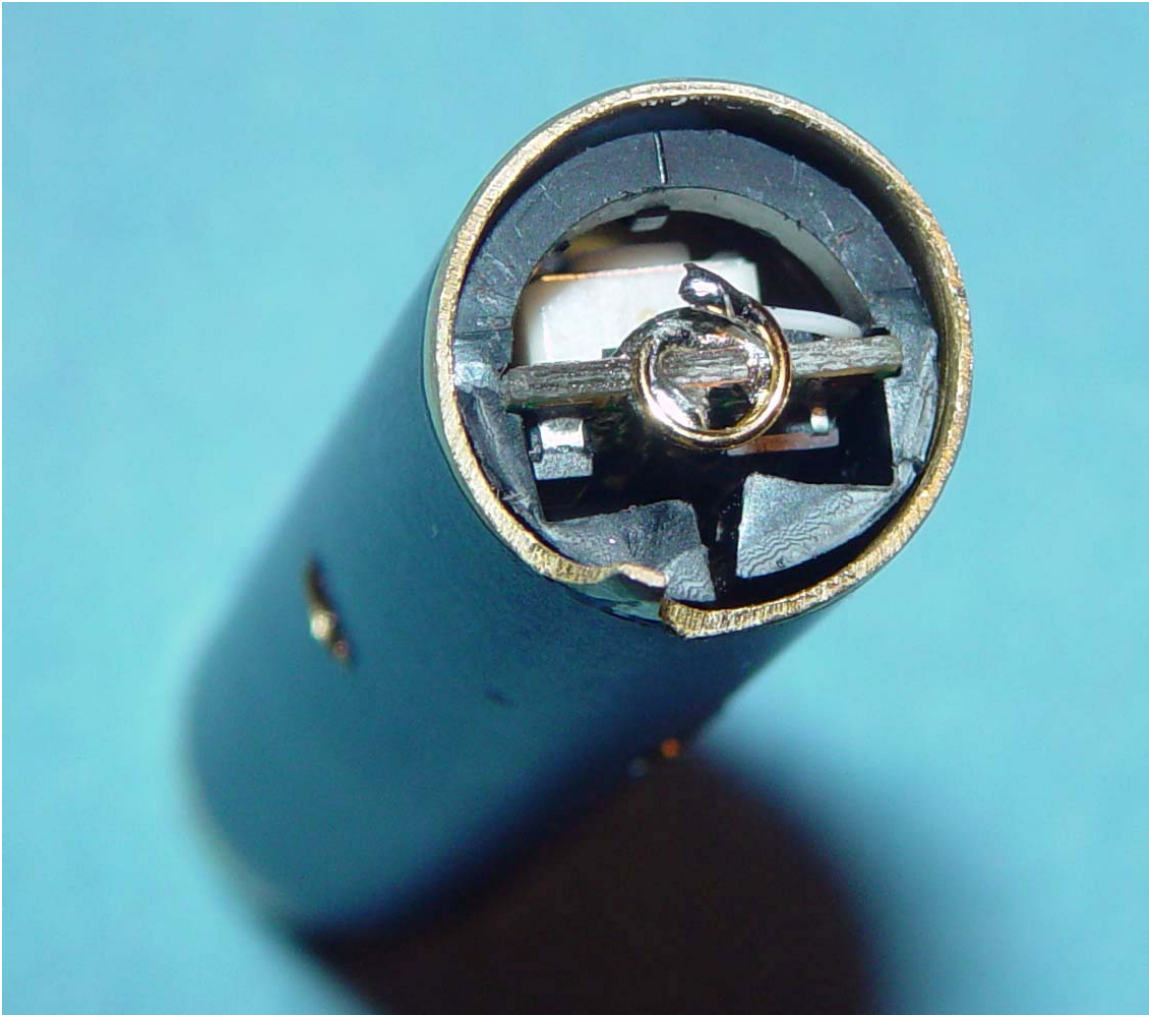
Two modifications are made to the laser pointer module before it is pressed back into the cut-off tube body. First, the spring is cut so that only about  $\frac{1}{2}$  turn is left attached to the circuit board. This half-turn of spring makes a convenient place to solder the negative power supply lead wire. The other modification is to add a small jumper that bypasses the switch on the laser module circuit board so that the laser will be on any time power is provided to the board. The figure below shows the modified laser modules used in the prototype aimer. The added switch-bypass jumper is a small white wire near the top right of the circuit board.



Before the laser module is pressed back into the cut-off tube body, the tube body is modified to provide a tab for soldering the positive power supply lead wire. Use a grinder to remove about  $\frac{1}{4}$ " of the rear of the tube body, leaving a  $\frac{1}{16}$  to  $\frac{1}{8}$ " wide tab on the side of the tube opposite the hole for the switch. The figure below shows the modified tube body after the laser module has been pressed back in. The soldering tab left on the tube body is at the bottom right.



Here is an end view of the modified laser pointer after the laser module has been pressed back into the cut-off tube body.



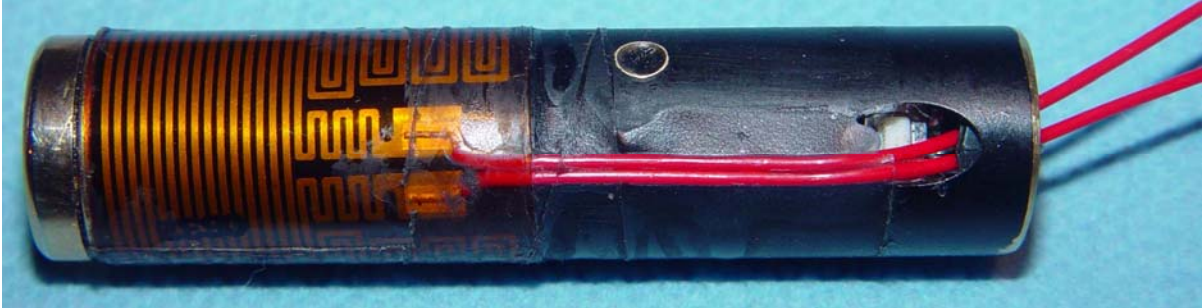
Step 2: Bonding the foil heaters onto the modified laser module assembly.

The laser pointer modules do not work well at low temperatures. Since the aimer must work in low temperature environments, we use a thin foil heater (Minco HK5163R5.6L12A) bonded to the laser module tube to keep the laser warm.

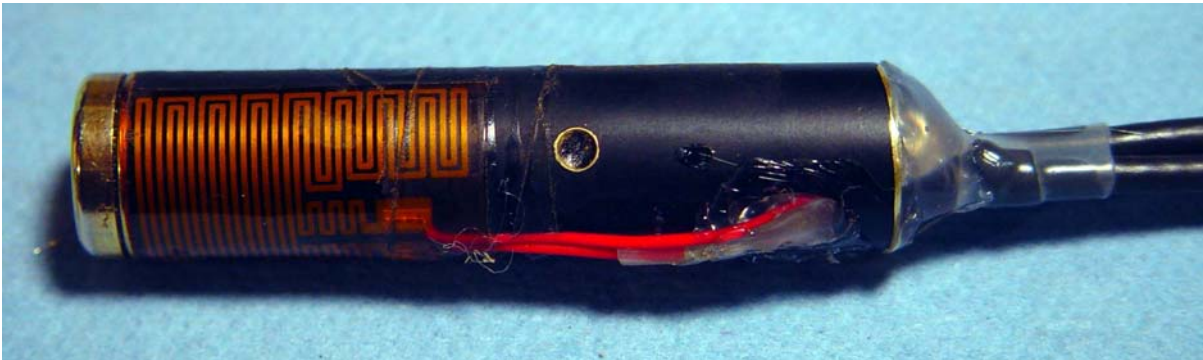
To maximize thermal conduction between the foil heater and the laser tube body, the thickness of the adhesive layer should be kept to a minimum. On the prototype aimer, the heater was bonded to the laser body tube with MGS L-285 laminating epoxy resin mixed with H-285 hardener per the manufacturer's recommendation. (MGS laminating resin and hardener is available from Aircraft Spruce and Specialties, [www.aircraftspruce.com](http://www.aircraftspruce.com))

The heater should be positioned so that the lead wires can be passed through the hole that originally contained the switch for the laser pointer. This provides some stress relief for the

wires. A thin layer of mixed epoxy is brushed onto the laser body, and then the foil is applied and held in place with a couple of wraps of Teflon tape. All air bubbles should be eliminated from the adhesive layer to ensure good thermal contact. The picture below shows the laser tube after bonding the foil heater in place.

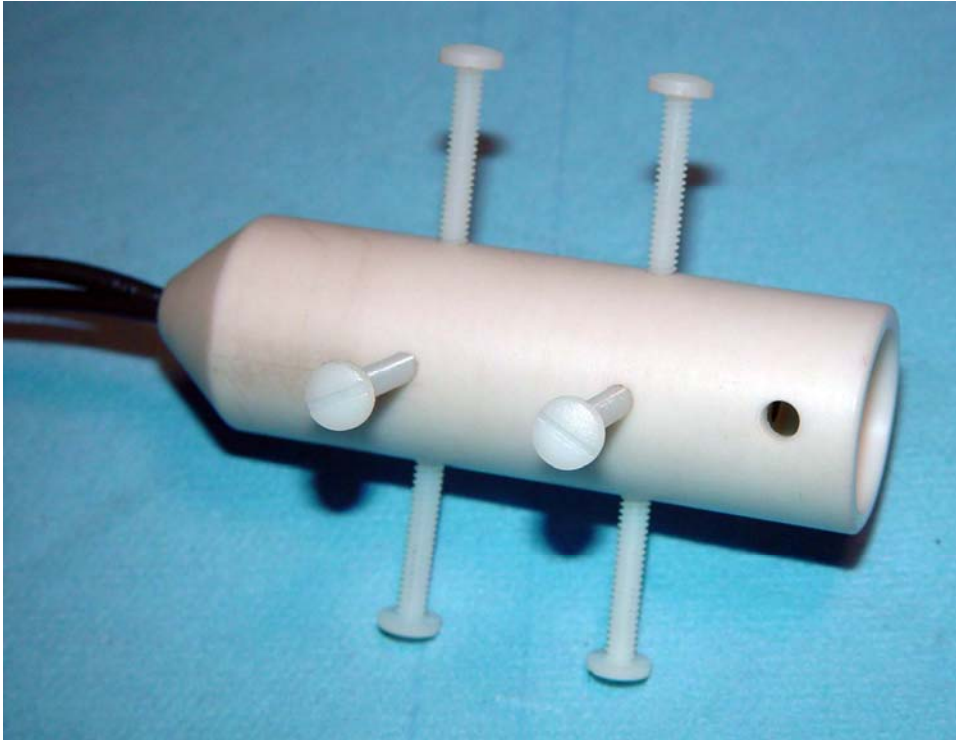


After the heater adhesive is cured, the wire pigtail for the heater and laser can be attached. The prototype device uses Belden 88444 4x22AWG cable for pigtails. The positive lead for the laser is soldered to the tab left on the tube body. The negative lead for the laser is soldered to the spring on the circuit board. The polarity of the heater wires doesn't matter, so long as neither of them is electrically connected to the laser tube or any other part of the laser module assembly. Heat-shrink tubing should be used as necessary to insulate the connections from each other and for stress relief of the wires. Once the soldering is finished, a hot glue gun is used to seal up all openings on the laser module so that the potting adhesive used later in the assembly does not penetrate into the laser assembly. Hot glue can also be used as stress relief for the wires. The picture below shows the completed module just prior to mounting in the Delrin sleeve.



Step 3 – Flex-mounting the laser assembly into the Delrin sleeve.

The laser module is now mounted into a Delrin sleeve in a manner that will allow adjustment of the laser so that it is coaxial with the outside surface of the Delrin sleeve. The module is inserted into the sleeve with the lead wire extending out through the hole provided in the sleeve. Eight plastic screws suspend the laser module in the Delrin sleeve. These screws **MUST** be plastic because they will be left in place, and metal screws would have too much thermal conductivity. Metal screws might also damage the Minco foil heater. The picture below shows the laser modules mounted in the Delrin sleeves with the adjustment screws.



Step 4 – Rough alignment of the laser module in the Delrin sleeve.

To align the laser module in the sleeve, mount the Delrin sleeve in a collet in a lathe and rotate the spindle by hand. A small 3V power supply is needed to illuminate the laser for the alignment. A convenient one like that shown below can be made from the unused portion of one of the laser tubes that was cut off by adding a couple of screws into a machined insulating cap that fits onto the cut-off end of the laser tube.



Start by adjusting the screws so that the laser beam strikes the center of the lathe tail stock as the stock is moved from close to the laser to the far end of the lathe. The most efficient alignment procedure is to move the target close to the laser and adjust the front adjustment screws to center the beam (the ones closest to the open end of the Delrin sleeve). Then move

the target far away and adjust the rear screws to again center the beam. Two or three iterations will have the beam pretty well co-axial. Once the alignment is close, remove the tail stock from the lathe so that beam will project at least 5 meters. Rotating the spindle by hand will move the beam in a circle. Adjust the screws so that the beam is at the center of this circle, and once this is done the beam should not move as the spindle is rotated. If the beam is centered at a point close to the laser and at another point far from the laser, then the beam is coaxial to the lathe spindle and hence to the exterior surface of the Delrin sleeve.

#### Step 5 – Bonding the cylindrical lens into the laser assembly

A cylindrical lens converts the pencil beam from the laser into a “fan” of light that will project a line on a target surface. Insert the lens into the lens mount holes in the Delrin tube. Mix a small amount of MGM epoxy in a suitable container. Using a toothpick or hypodermic needle, push the lens slightly to one side, apply some adhesive to the exposed surface of the mounting hole, and then re-center the lens. Repeat the process on the other side so that the lens is bonded on both sides and the lens forms an airtight seal with the Delrin sleeve. Recenter the lens and allow the adhesive to cure.

#### Step 6 – Final alignment of the lasers in the laser assemblies

Repeat the alignment procedure in the lathe to get final alignment of the laser prior to potting. The laser assembly now projects a line instead of a dot. All that is required is that the laser be adjusted so that the line rotates about some point on the target as the lathe spindle is turned. If the laser is mis-aligned, then the line will not rotate about a point, but will instead circle around it. Once final alignment is complete, take care not to bump the assemblies or turn any of the screws as this could cause the laser to move in the Delrin sleeve. The assemblies should be mounted in a potting fixture with the open end up.

#### Step 7 – Potting the lasers in the Delrin sleeves

Using a hot glue gun, apply a small amount of hot glue around the pigtail where it exits the Delrin sleeve. This will prevent leakage of potting material around the pigtail.

With the laser assemblies held in a fixture with the open end of the Delrin tube up, mix a batch of MGS L-285 resin and H-287 hardener in a 100:40 ratio by weight. The H-287 hardener should be used for this step because it cures much more slowly than the H-285 hardener, which minimizes the heat buildup in the potting. Once the epoxy is thoroughly mixed, add SiO<sub>2</sub> microballoons until the material has a “soft peak” consistency, similar to whipped cream. For the prototype device, the proper amounts to fill one of the laser assemblies was 8.0g of L-285 resin, 3.2g of H-287 hardener, and 1.8 to 2.0 g of Silica microballoons. Having a high volume fraction of microballoons causes the potting material to have good insulating properties, as well as giving it a lower coefficient of thermal expansion.

Once the microballoons are thoroughly mixed into the mixed epoxy, place the potting material into a hypodermic syringe and inject it into the hole provided for this purpose in the rear of the Delrin sleeve. The potting material should be injected until it is just below the

front surface of the laser pointer module. Once the potting is complete, set the assemblies aside for at least 24 hours so that the potting material will be completely cured.

#### Step 8 – Alignment and operational check

Once the potting material is cured, cut the adjustment screws off at the external surface of the Delrin sleeve, making sure that no part of the cut screw extends beyond the outside surface of the Delrin. A razor blade works well for this.

Place the assembly in the lathe and using the procedure of Step 6, verify that the laser still works and that it is still aligned properly. If doesn't work, or if it is misaligned, then the assembly must be discarded.

#### Step 9 – Bonding the Sapphire windows.

If the laser assembly passes Step 8 satisfactorily, then the sapphire window can be bonded in place to completely seal the assembly from the environment. To minimize thermal conductivity and to ensure that no condensation can form inside the laser assembly, the windows are bonded in place in an Argon atmosphere so that the laser assembly is filled with Ar instead of air. This can be done in an Ar-filled glovebox, or by doing the assembly inside an Ar-flooded plastic bag. Assembly of the prototype aimer was done using the plastic bag method.

Mix a small amount of MGS L-285 resin and H-285 hardener in a 100:40 ratio by weight. Apply a small amount of adhesive to the seat for the window machined in the Delrin sleeve, taking care not to get adhesive on the laser module or on the cylindrical lens. Apply the adhesive all the way around the perimeter of the window seating surface, then insert the window. Clamp the windows in position until the adhesive cures so that if the temperature changes the window won't be expelled by the expanding Ar gas in the laser assembly. It is best if the temperature is held constant during the curing of the adhesive.

The picture below shows the completed laser assembly ready for insertion into the shaped charge mount.



Step 10 – Bonding the laser assemblies into the shaped charge holder.

An alignment tool having the same diameter as the shaped charge that projects a laser beam along its axis to simulate the jet is used to align the laser modules when they are bonded into the shaped charge holder. A picture of this alignment tool is shown below.



Set up a target card a short distance from the front of the shaped charge holder. Apply a small amount of adhesive (MGS L-285, H-285 mix, with enough microballoons added to give it a thin paste texture) to the inside of the mounting holes for the laser modules. Insert the modules, rotating them so that the line from each laser assembly passes through the shaped charge axis. Note that the cylindrical lenses are offset so that the beam is biased toward one side of the laser assembly axis. The beams should be biased toward the shaped charge axis. The two lines projected from the laser assemblies should cross exactly at the dot from the laser in the alignment tool.

Check to make sure that this alignment is maintained at all distances. If it is not, then the holes in the shaped charge mount are not parallel.

The picture below shows the assembled aimer with the lasers operating. Note that the aimer can be aligned to two different targets, as shown in the picture. The alignment tool laser is not operating in this image.



#### Step 11 – Connecting and potting the wires

The wires to the laser assemblies should be connected to a 10' length of Alpha Wire 1896/4C, 4x20AWG cable as shown in the wiring diagram. Once soldering and heat shrink are completed, pot the cabling into the slots on the shaped charge holder using epoxy. This potting provides strain relief so that the wires cannot be accidentally pulled out of the laser modules.

#### Step 12 – Install the connector

Install the connector onto the free end of the aimer supply wire per the wiring diagram.

The wiring diagram can be found in Appendix C of this report.

## Appendix C – Wiring Schematic for Laser Aimer

### Alignment Module Power Supply Schematic

